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UNITED STATES PATENT APPLICATION

of

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for

THREE DIMENSIONAL HIGH INDEX OPTICAL WAVEGUIDES BENDS AND SPLITTERS

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PRIORITY INFORMATION

This application claims priority from provisional application Ser. No. 60/253,604 filed November 28, 2000.

BACKGROUND OF THE INVENTION

The present invention is in the field of optics, specifically in integrated optics bends, splitters, and resonators. High index contrast waveguides provide high-density integration for optical networking and on-chip optical interconnects. One of the main features of high index contrast waveguides has been the demonstrated ability to manufacture low loss compact bends, splitters and resonators.

It is has been shown that the bending loss for a 1 μm radius of curvature bend in a silicon high index contrast strip waveguide is 0.5 dB/turn. However, this number is still much larger than the theoretically predicted bending loss. Furthermore, a splitting loss of 0.2 dB has been reported with a Y-split angle of 2 degrees. This small split angle results in a rather long, 30 micron, Y-splitter.

To address this problem, the article C. Manotalou et al., "High-Density Integrated Optics", Journal of Lightwave Technology, 1999, vol. 17, no. 9, proposed two dimensional bends and splitters based on a two-dimensional high transmission cavity (HTC) with a polygonal shape. High transmissions cavity bends and splitters were designed with bandwidths exceeding 100 nm and transmission rates greater than 95%.

The two dimensional high transmission cavities (HTCs) are shaped as polygons, with one

side at a 45 degree angle to the incoming and outgoing waveguides. A 2-D HTC bend may be formed by adding two waveguides together, thus forming two coupled resonators.

There was a need in the art to provide a way to split incoming optical signals in a waveguide into two separate and distinct signals. Specifically, 2-D HTC Y-splits were important because they accomplished that task of splitting an incoming signal into two separate signals. The geometry of the 2-D Y-split HTC was such that the splitting point was 90 degrees and the splitting area was small. The 2-D Y-splitter HTC did this most efficiently, because the two splitted signals were directed away from each other.

SUMMARY OF THE INVENTION

Accordingly, the invention presents a novel method and system for developing extremely small high index contrast bends, splitters, and resonators using a structure known as a high transmission cavity in three dimensions.

According to one aspect of the present invention, an optical cavity waveguide structure is provided. The optical cavity waveguide structure includes an input port for receiving input optical signals from a first waveguide. The optical cavity waveguide structure also includes an interconnecting structure that receives said input optical signals and interconnects said first waveguide to a second waveguide, the interconnecting structure further includes at least 4 straight edges that are orthogonal and of a finite width. The optical cavity structure further includes an output port coupled to the interconnecting structure for providing the second waveguide with the input optical signals.

According to another aspect of the invention, an optical splitter device is provided. The optical splitter device includes an input port for receiving input optical signals from an input

waveguide. The optical splitter further includes a splitting structure that receives the input optical signals and splits the input signals into at least two separate signals that are directed to at least two separate waveguides. The splitting structure also includes at least two separate optical cavities connected to their sides that are orthogonal with a finite width.

According to another aspect of the present invention, an optical resonator is provided. The optical resonator includes a plurality of straight edge waveguides. The optical resonator also includes a plurality of interconnecting elements for interconnecting said plurality of straight waveguides to form said optical resonator, wherein said interconnecting elements include at least four straight edges that are orthogonal and of a finite width.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a three dimensional (3-D) HTC bend;

FIG. 2 illustrates a 3-D HTC T- splitter;

FIG. 3 illustrates HTC resonator structure, and

DETAILED DESCRIPTION OF THE INVENTION

FIG 1 illustrates a 3-D HTC bend design. The 3-D HTC bend 2 includes a two dimensional (2-D) HTC bend 3 that includes a quarter of an octagon with an input waveguide 6 and an output waveguide 4 attached to two of the facets of the resulting five sided sections 8, 10, 12, 14, and 16. The 3-D HTC bend 2 also includes four orthogonal straight edge sides 8, 10, 12, and 14. The fifth side 16 of the 3-D HTC bending structure is aligned at an angle of 135 degrees from both of its adjacent sides 12 and 14. The 2-D HTC bend 3, while useful theoretically, has no 3-D structure and cannot be easily used in integrated optics applications in an obvious way.

The use of a 3-D HTC bend 2 is an attempt to extend the 2-D HTC bend 3 to three dimensions by utilizing the same five-sided polygon with a finite thickness 18.

The 3-D HTC bend 2 may be understood in two ways. The first is to look at the 45-degree facet 16 as a reflector. As light enters through the input waveguide 6 it is reflected off the 45-degree facet 16. The inside of the 3-D HTC bend 2 has extra material that acts to pull down the mode away from the outer wall, improving the mode matching of the bending section with respect to the input and output waveguides and 6 and 4, which in turn reduces the loss of the bend. The other way to understand the 3-D HTC bend 2 is to analyze it as a low load Q resonator. The resonator is strongly coupled to the input and output waveguides 6 and 4 resulting in its low load Q and large transmission bandwidth.

The 3-D HTC bend 2 only includes straight edges 8, 10, 12, 14, and 16, and thus, reduces that amount of loss in the structure. For purposes of illustration, the 3-D HTC bend 2 may be used with polySi and SOI (silicon on insulator) waveguides either as an input waveguide 6 or an output waveguide 4. The bending loss associated with a 3-D HTC bend 2 fabricated with polySi is 0.3 db/turn. That is smaller than the loss value obtained for a 1 micron radius of curvature round bend on the same die. These numbers are impressive given that the area up by the 3-D HTC bend 2 is smaller than the area taken up by the round bend. The thickness 18 may be approximately 0.2 μm. In general, the thickness will be chosen to maintain the lowest number of modes.

FIG. 2 illustrates a 3-D HTC T splitter. The task of the 3-D T-splitter 42 is to split incoming optical signals from the input waveguide 40 into two separate optical signals. These optical signals are then directed to the two output waveguides 44 and 46 of the 3-D HTC T-

splitter 42. The aligning together the largest sides of two 3-D HTC bend structures 48 and 50 form the 3-D HTC T-splitter.

One of the main advantages of utilizing the 3-D HTC T-splitter 42 over a traditional Y-splitter is its small size, since a Y-split must incorporate a small split angle and larger bends to maintain its low loss nature. On the other hand, in a T-split structure the input waveguide exits opposite the two output waveguides, reducing the need for bends. The 3-D HTC T-splitter 42 also has a considerable loss advantage when compared to other traditional T-split structures, the latter of which involves the incoming waveguide terminating abruptly into the output waveguides. Another big advantage of the 3-D HTC T-splitter 42 is that it is more tolerant of fabrication errors then a traditional Y-split. Just like the aforementioned 3D-HTC structure, the 3-D HTC T-splitter has a finite thickness

For illustrative purposes, the invention utilizes polySi and SOI (silicon on insulator) waveguides as either an input waveguide 40 or output waveguides 44 and 46. The polySi and SOI waveguides have a silicon (n=3.48) core, a bottom cladding of silica (n=1.48) and top cladding of air. The transmission loss of the inventive 3-D HTC T-splitter 42 fabricated in polySi is approximately –1.2 dB, which is large when compared to the –0.15 dB loss extracted for the Y-split fabricated in the same mask. It may be shown that this loss number will improve with a more efficient design. The thickness of the 3-D HTC T-splitter may be 0.2μm. The thickness is chosen to maintain a low number of modes. The 3-D HTC T-splitter 42 represents the ultimate 90-degree split since they occupy a very small area. The power uniformity of these devices is good due to the inherent symmetry of the device. The benchmark $\frac{\sigma}{\mu}$ (standard

deviation/mean) to measure deviations in the split ratio, was 0.2, which is significantly better than the traditional Y-splits.

FIG. 3 illustrates an HTC traveling wave resonator. The HTC resonator 52 is a traveling waveguide resonator that includes several straight edge waveguide sections 54, 58, 62, and 66 and an equal number of HTC bends 56, 60, 64, and 68 to connect the sections 54, 58, 62, and 66. The HTC resonator 52 may be formed with more waveguide sections and 3-D HTC bends. However, the HTC resonator 52 is most efficient when there are equal numbers of straight edge waveguide sections and 3-D HTC bends. Also, this resonator can be used to measure the loss associated with HTC bends and as a method for making traveling waveguides with anisotropic etchants.

For illustrative purposes, the HTC traveling wave resonator 52 is implemented in polySi and SOI materials utilizing the same aforementioned HTC bend discussed above. The 3-D HTC bends 56, 60, 64, and 68 interconnect the waveguide sections 54, 58, 62, and 66 in a closed loop formation. The HTC wave resonator is much easier to fabricate than other standard resonators. As mentioned above, the fabrication of the 3-D HTC bends 56, 60, 64, and 68 do not require an extensive amount of fabrication, and the waveguide sections can be any standard straight edge waveguides. The measured Q for such an arrangement 52 is 750 and loss of the HTC bends 56, 60, 64, and 68 was extracted to be 0.2 dB/turn, which is consistent with the number discussed above. Thus, the HTC traveling wave resonator 52 is an efficient resonator.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is: